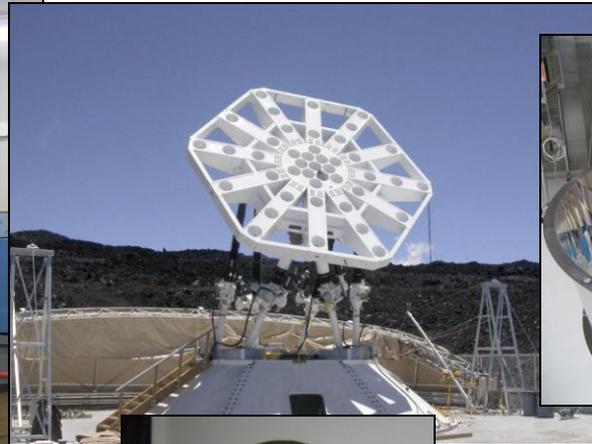


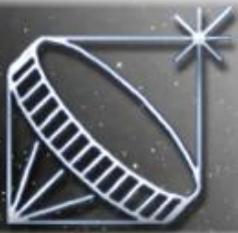
**Composite
Mirror
Applications Inc.**

Mirror Tech Days

July 31 - August 2 2007



1638 S. Research Loop, # 100
Tucson, Arizona 85710
(520) 733-9302 Ph.
(520) 733-9306 Fax
<http://www.compositemirrors.com>



*Composite
Mirror
Applications Inc.*

About CMA

CMA, Inc.

- Incorporated August 1991*
- 9,000 ft² Facility*
- Located in Optics Capital, Tucson, AZ*



**Composite
Mirror
Applications Inc.**

Primary Focus

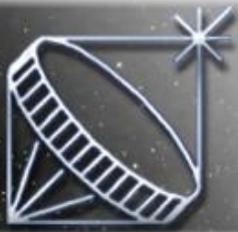
- **What we do:**

Design, prototype and manufacture unique custom high-quality lightweight optics and optical systems from Carbon Composite Materials. Activity supported by ongoing R&D effort.

- **Goal:**

Demonstrate relevance to DoD or Homeland Security applications CMA's precision composite mirror/system technology supporting:

- Large Lightweight Optical Tracking Telescopes
- FLIR systems
- Earth and Space-based Vis.-IR-Microwave imaging Applications, Sensors and Instrument Technologies.
- Lightweight, durable optical, inertial platforms
- Space and Ground Communications, Lasers and Lidar Systems
- Power generation and Transmission
- ISR Sensors and Platforms

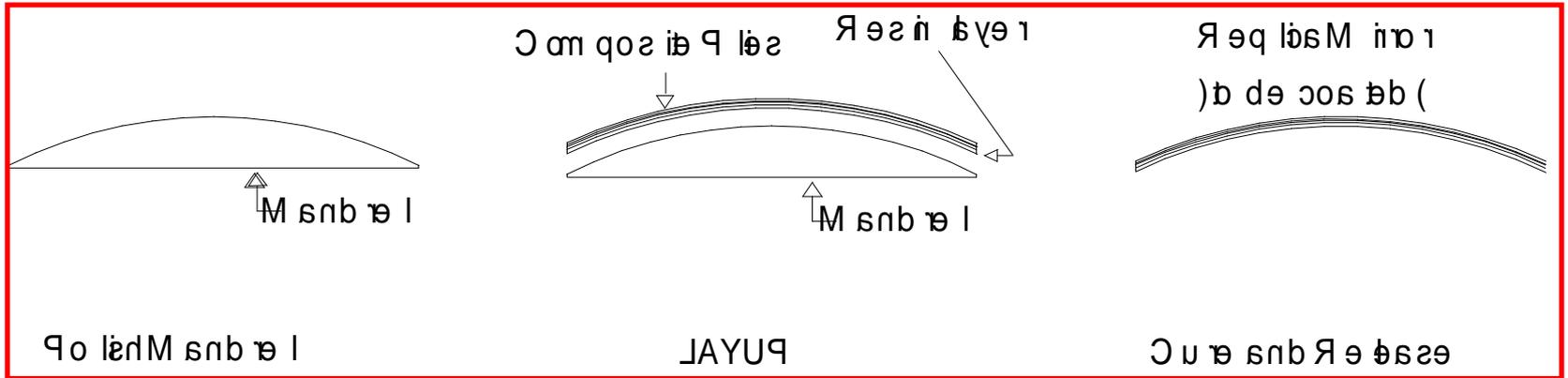


**Composite
Mirror
Applications Inc.**

Technology Overview

High Accuracy Replication

What are Composite Mirrors?

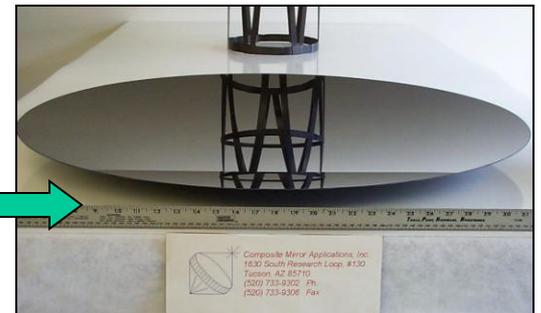
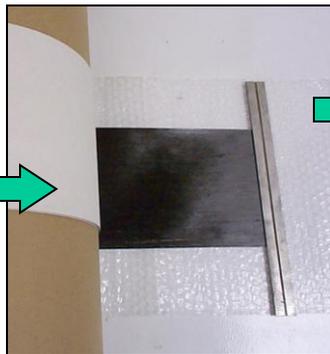


Mandrel

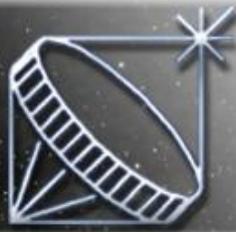
CFRP

Lay-Up

Finished Product



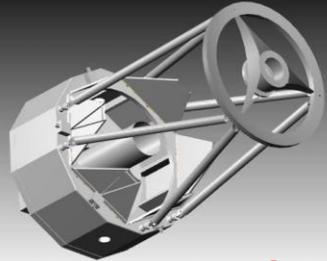
Composite Mirror Applications, Inc.
1630 South Research Loop, #130
Tempe, AZ 85280
(520) 733-9302 Ph.
(520) 733-9306 Fax



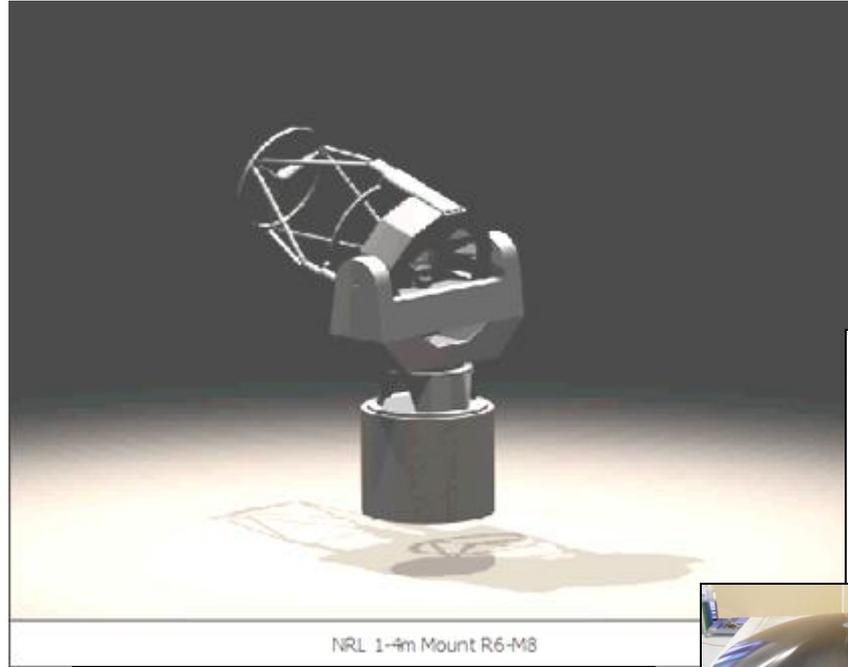
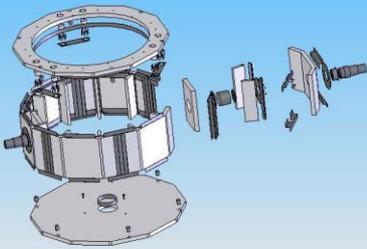
**Composite
Mirror
Applications Inc.**

Capability Overview

Design/Analysis Capability



**SolidWorks CAD,
Cosmos FEA**



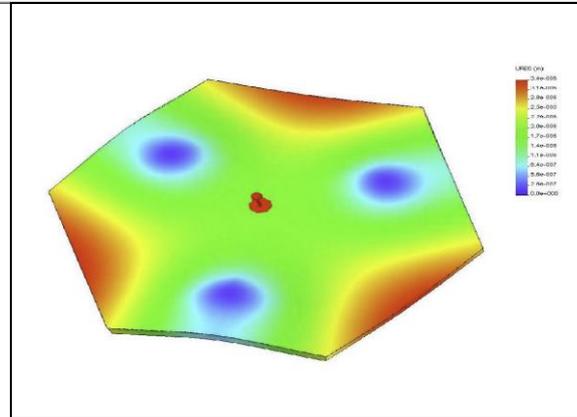
NRL 1-4m Mount R6-M8



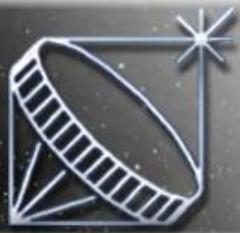
Breadboards



**APEX
Subreflector
and Wobbler**



**Build-to-Print Prototyping
in CFRP**



**Composite
Mirror
Applications Inc.**

Optical Coating and Vacuum Processes

1.8-meter Vacuum Deposition Chamber



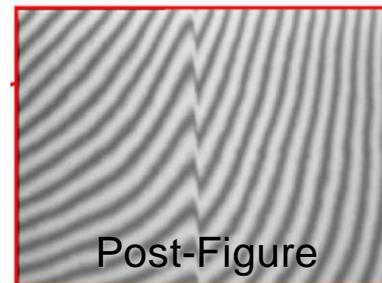
Coating/Process Development



Balzers
Coating
Chamber



LVH Coating
Chamber



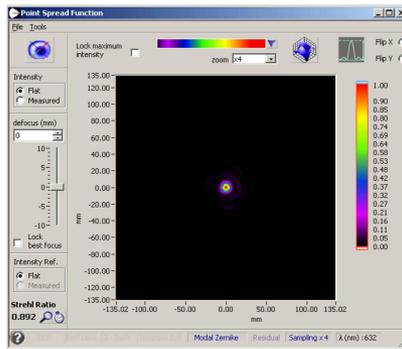
Post-Figure
Process



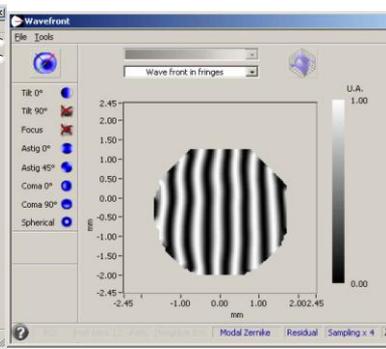


**Composite
Mirror
Applications Inc.**

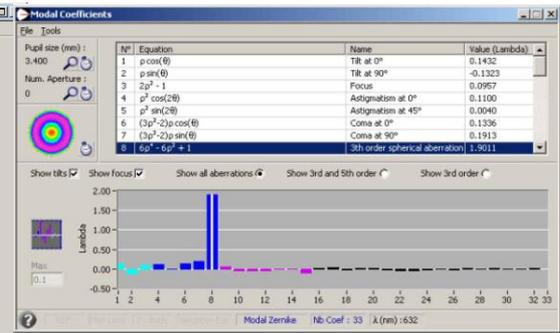
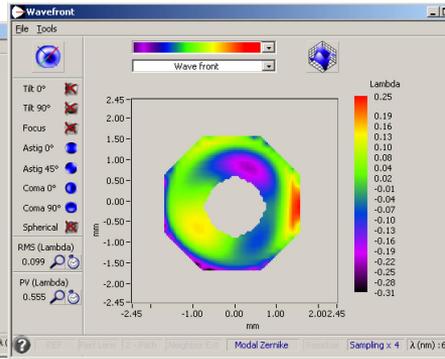
Optical Testing



PSF of the wavefront for 6" spherical CFRP mirror, #6.2

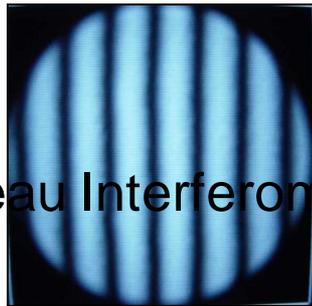


Synthetic fringes of CFRP 6" sphere, only tip, tilt and piston terms removed



First 32 Zernike terms for 16-inch CFRP Cassegrain parabolic mirror wavefront.

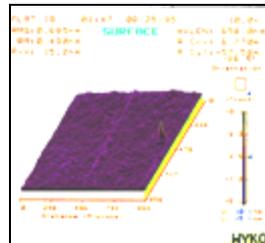
Shack-Hartmann Testing



Newton & Fizeau Interferometry

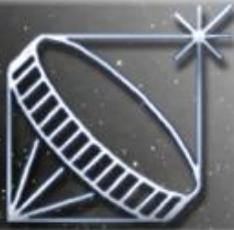


Ronchi



WYKO Topo 3-D

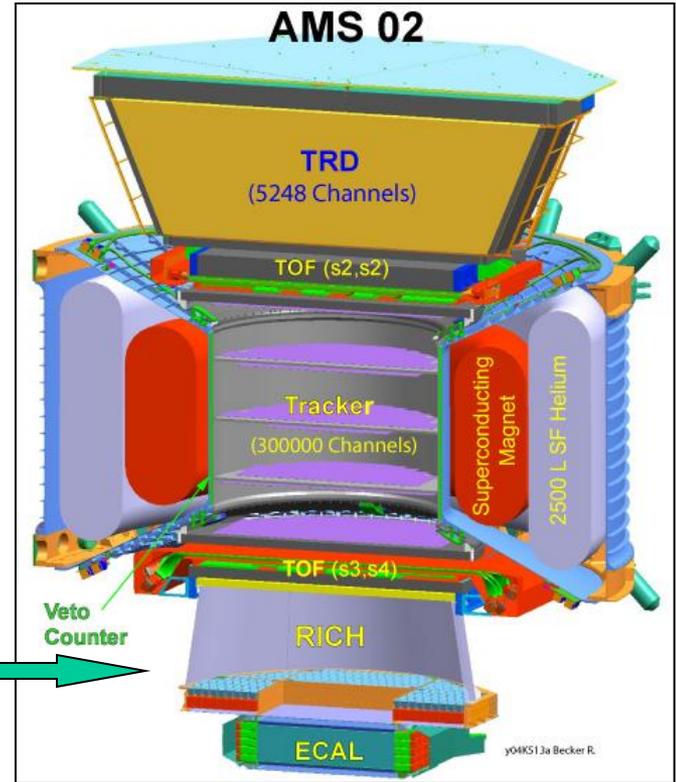
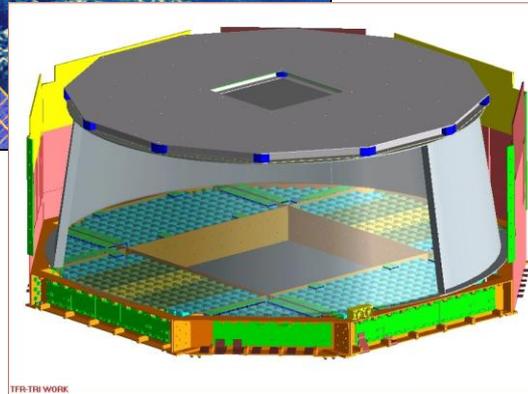
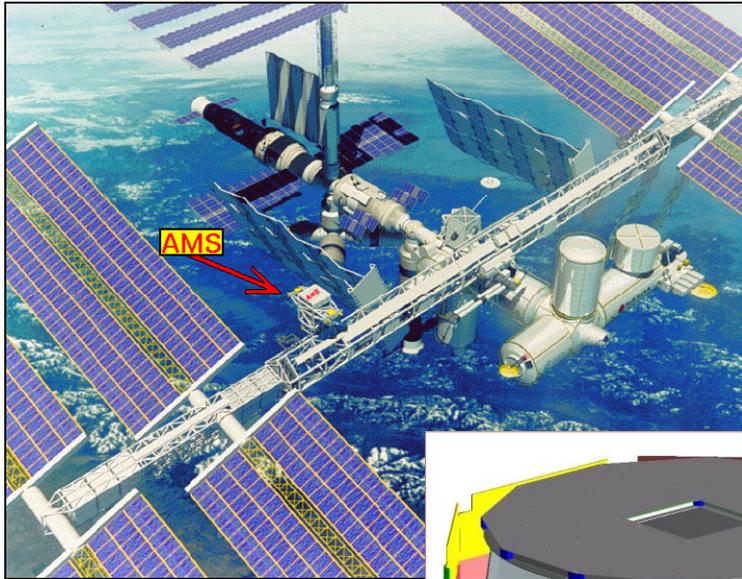
- Zygo Mark III Interferometer
- HASO 32 Shack-Hartmann wave front sensor from Imagine Optic, 32X32 array
- WYKO Topo 3-D Surface Measurement
- Fizeau Interferometer
- Ronchi Test
- Newton Interferometer for up to 60cm diameter



**Composite
Mirror
Applications Inc.**

Capability Overview

Space Flight Optics
Alpha Magnetic Spectrometer, AMS-02



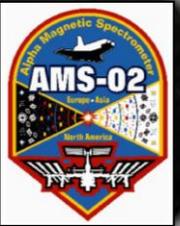
RICH Mirror produced in cooperation with Carlo Gavazzi Space for the Italian Space Agency. Mirror is 1.3 m diameter, conical surface. Mirror weight is 8 kg. Mirror is currently being integrated into the Alpha Magnetic Spectrometer, AMS-02, schedule for STS launch to the ISS in December 2008.



**Composite
Mirror
Applications Inc.**

Capability Overview

Space Flight Optics
Alpha Magnetic Spectrometer, AMS-02



CFRP mirror sample with PMT module in test set up. Optimized reflectivity for $\lambda=420\text{nm}$

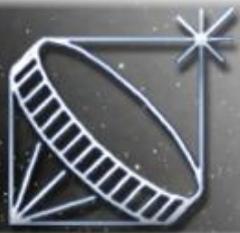


1.3m CFRP Rich Flight model after coating.



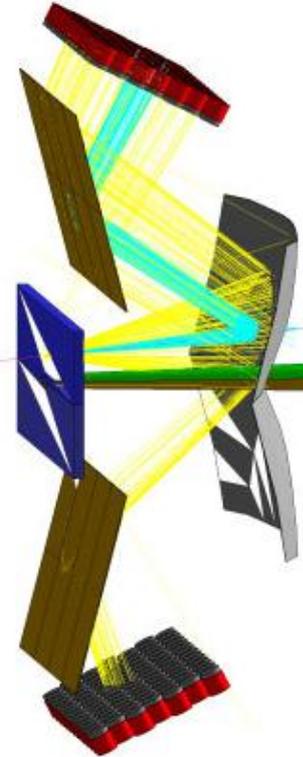
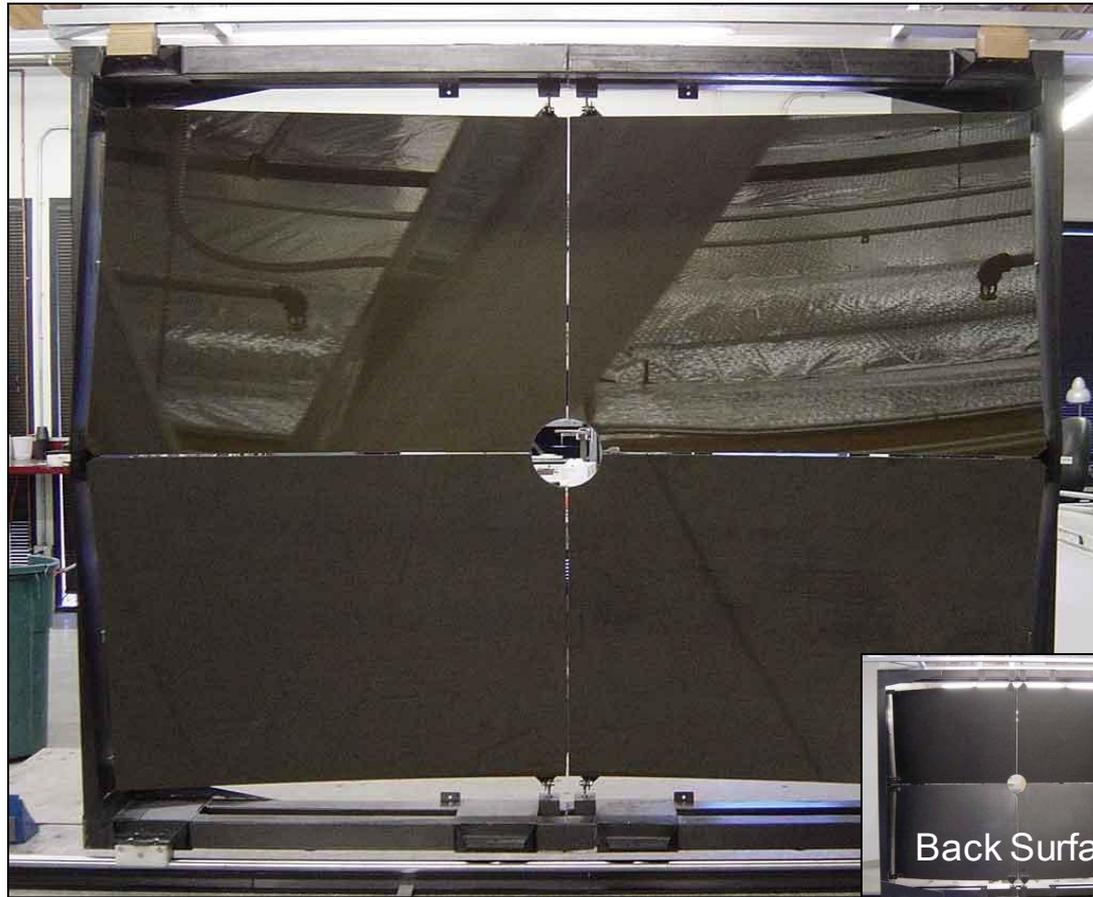
1.3m CFRP Rich Flight Model Completed



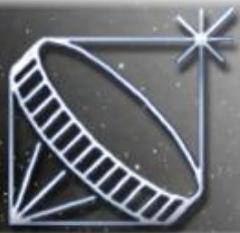


**Composite
Mirror
Applications Inc.**

**High Energy Physics
LHCb RICH 1
Mirror Assembly**

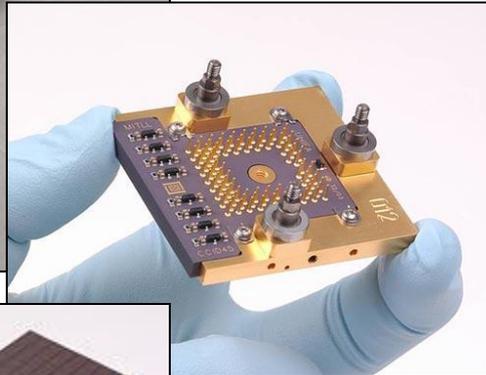
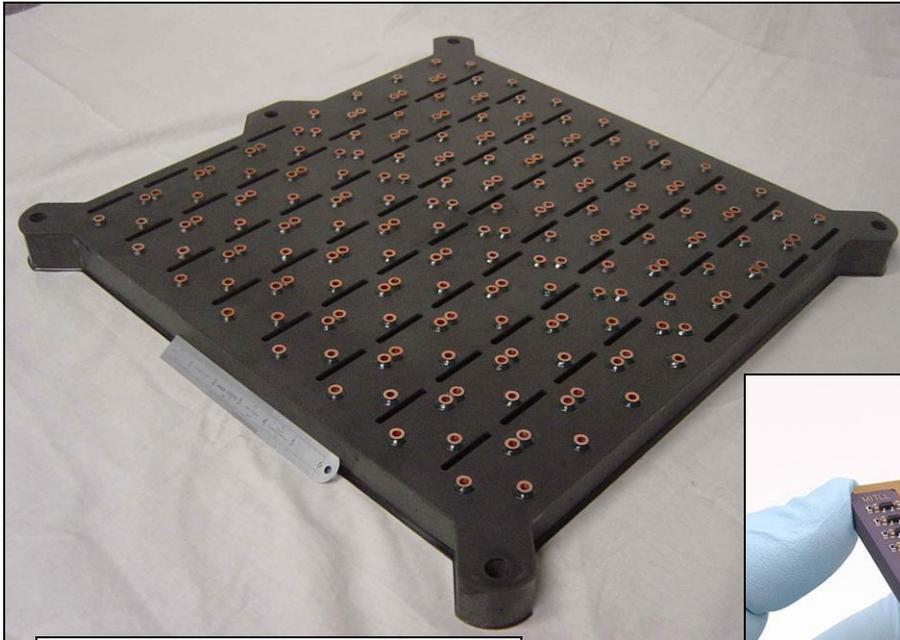


RICH mirror assembly for University of Bristol, Large Hadron Collider, LHCb experiment at CERN. The mirrors are spherical with an ROC of 2700mm, and areal density of 5 kg/m², 2 m² total reflective area, total weight 36 lbs. Reflectivity optimized for UV @ $\lambda=280\text{nm}$.



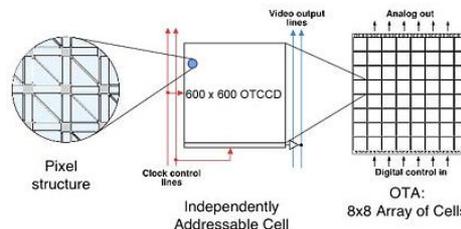
Composite
Mirror
Applications Inc.

CFRP Focal Plane Array



The Panoramic Survey Telescope and Rapid Response System, Pan-STARRS, will employ the largest CCD camera in the world,

1.4 *Gigapixels!* Under contract with IFA, University of Hawaii, CMA produced the 18" X 18" precision CFRP structure to hold the 64 8X8 Orthogonal Transfer Arrays, OTA's, CCD's shown inset. The CFRP structure has 192 oxygen-free copper inserts to mount each of the OTA's.





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Mirror
Applications Inc.**

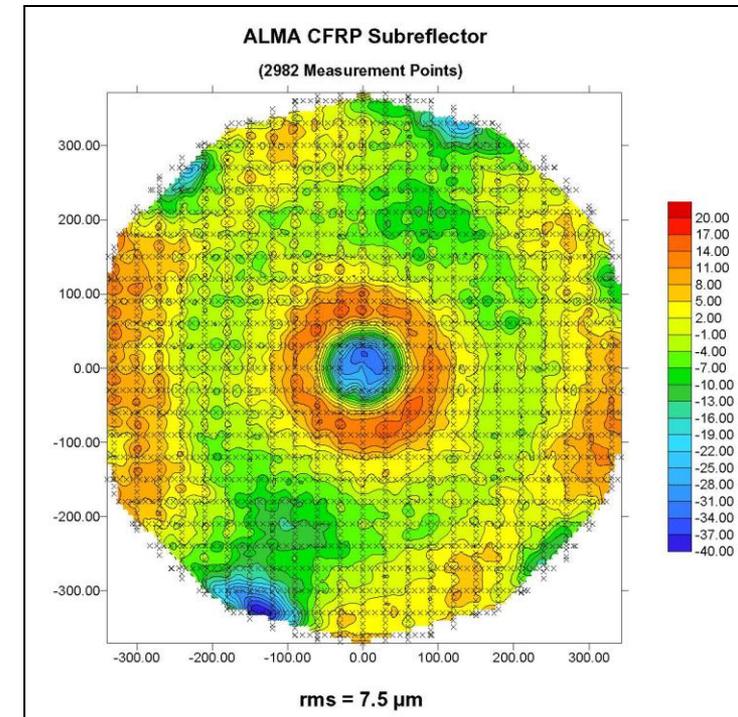
ALMA
Nutating CFRP
Subreflectors



**Atacama
Large
Millimeter /
submillimeter
Array**



750mm Diameter



CMA's produced 3 nutating (chopping) subreflectors for the ALMA US and Japanese Prototype 12m Telescope, 7.5 μ m rms, 12 lbs. A nearly identical subreflector was produced for the APEX Telescope as well, 7.0 μ m rms.



**Composite
Mirror
Applications Inc.**

Millimeter Wave Dishes

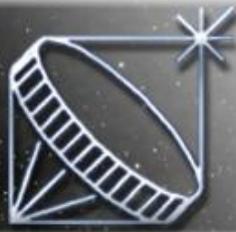
330 mm CFRP Dishes



320 mm Parabolic Dish Antennas
All Graphite Composite
Construction

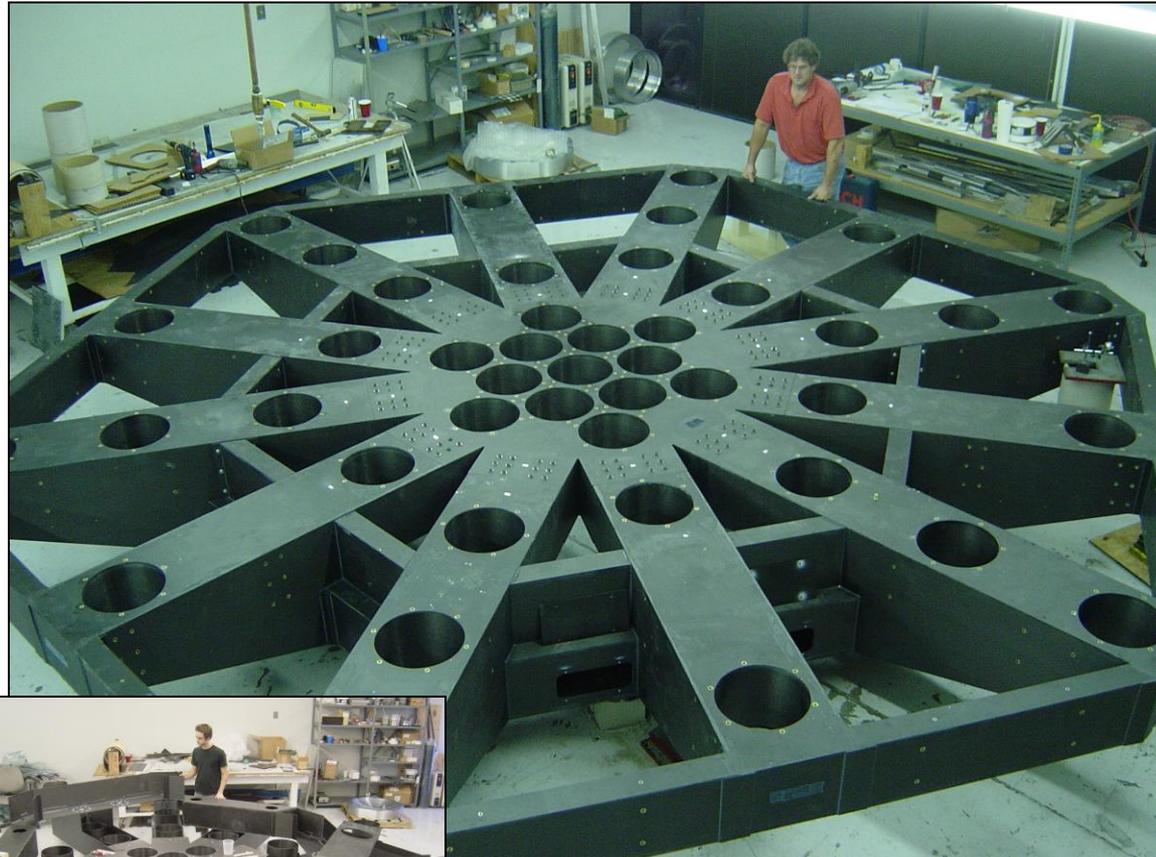


All CFRP 3mm-wave dishes, 330mm diameter, $f/0.35$ parabolic primary reflector, surface accuracy 1 micron rms. Right image shows dishes and receivers under test in Mauna Loa.



**Composite
Mirror
Applications Inc.**

Large CFRP Structures Experience AMiBA Telescope



AMiBA Telescope Platform, 6m all-CFRP composite, weight is 2,200 lbs, left images shows platform under construction at CMA, Tucson Az.

AMiBA Telescope
with 7 dishes, 60cm
diameter on site on
Mauna Loa October
2006

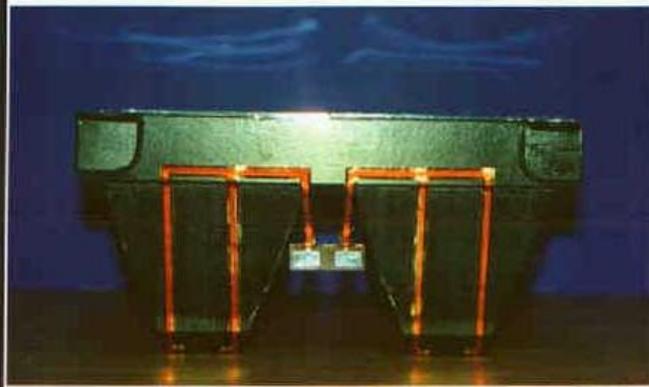




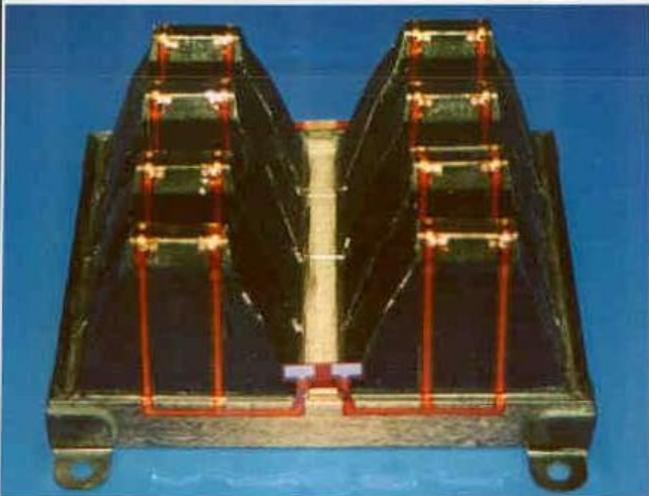
**Composite
Mirror
Applications Inc.**

GRIN Solar Concentrator

Spacecraft Power Generation

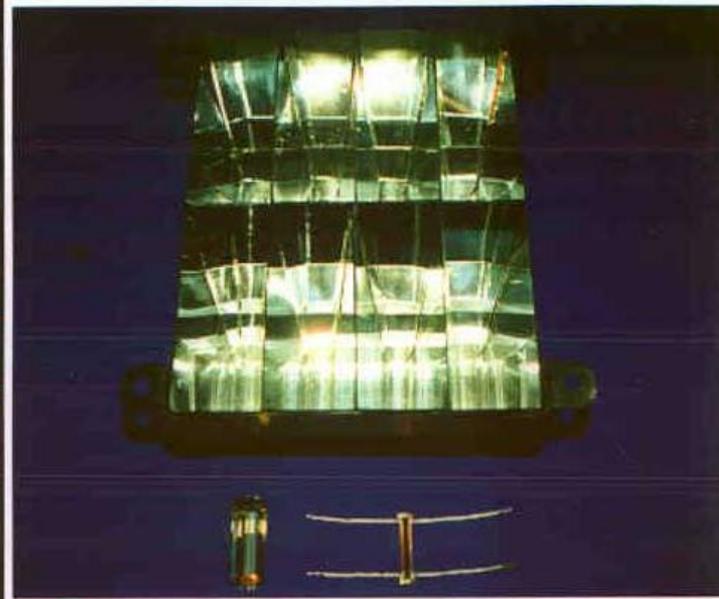


10 WATT SUBMODULE - SIDE VIEW



10 WATT SUBMODULE - BOTTOM VIEW

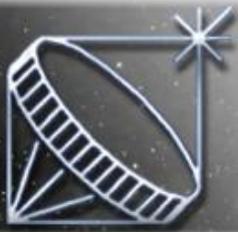
10 WATT SUBMODULE - COMPONENTS



GRIN SOLAR CONCENTRATOR 10 WATT SUBMODULE

APERTURE AREA: 300 CM²
CONCENTRATION RATIO: 50X
MJ SOLAR CELLS: GaInP₂ / GaAs
OPTICAL SYSTEM: 2 STAGE CONCENTRATOR
STRUCTURE: K1100 CARBON COMPOSITE

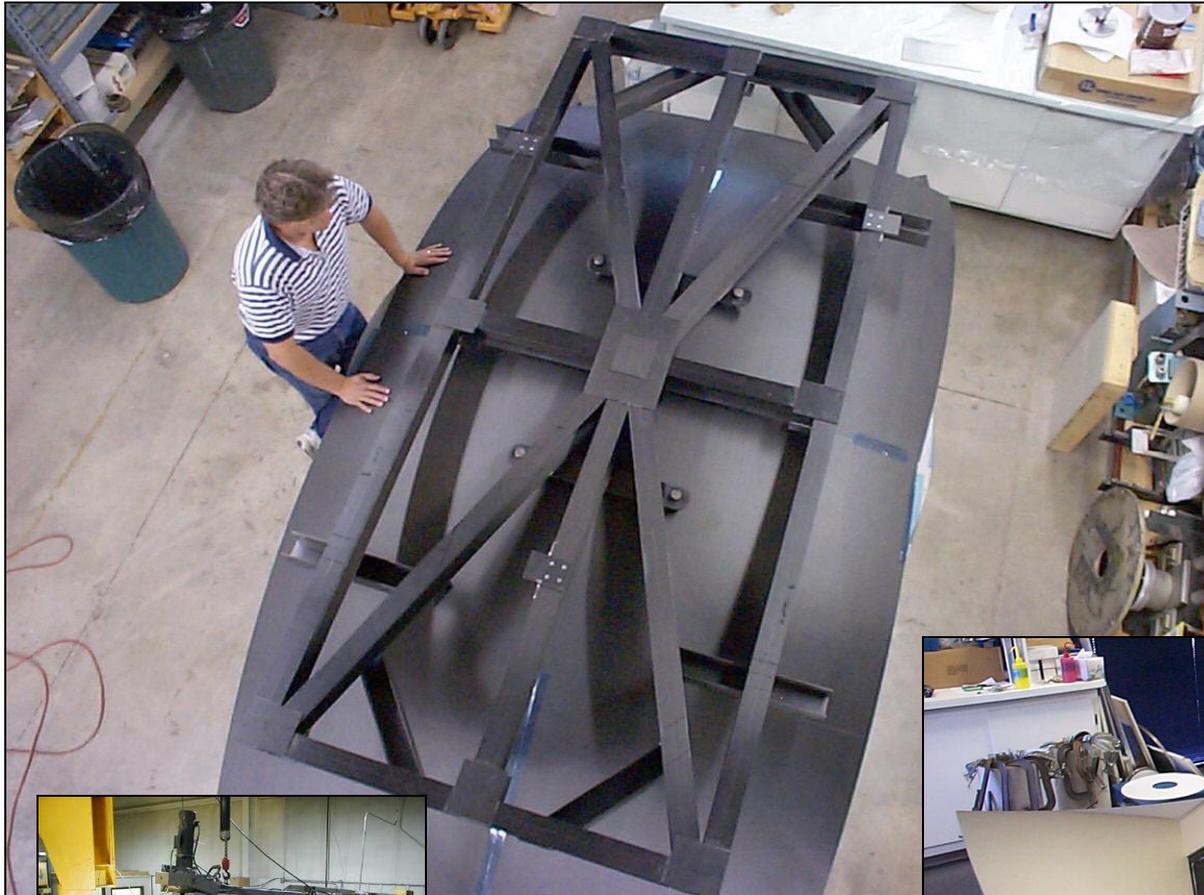
CMA produced, through DR Technologies and AFRL, a gradient index of refraction, GRIN augmented solar concentration onto a single crystal PV cell. Concentrator uses K1100, high thermal conductivity carbon fibers for high efficiency of the PV cell, GRIN and PV cell shown in bottom of upper right photo.



**Composite
Mirror
Applications Inc.**

Large Projection Mirrors

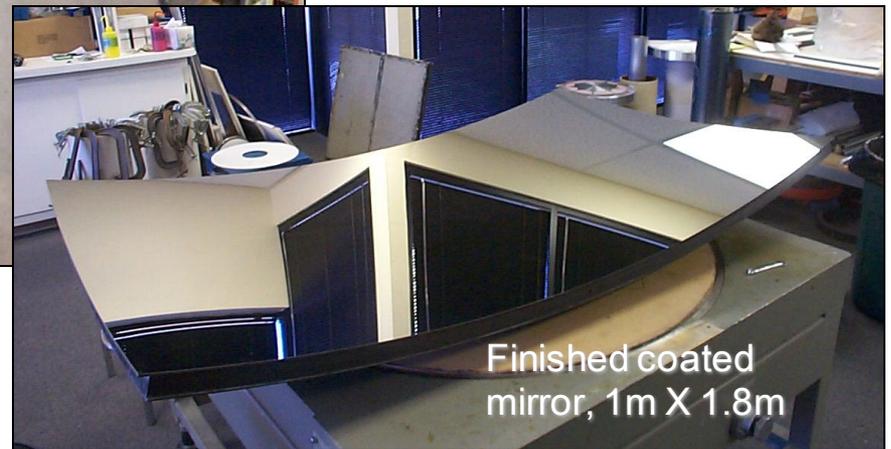
Flight Simulator Mirrors



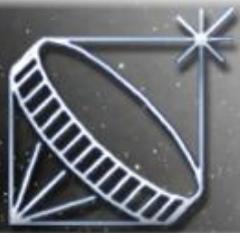
**Large CFRP Flight
Simulator Mirror
Demonstrator**



**100-inch Spherical
Mandrel, 86-inch ROC**



**Finished coated
mirror, 1m X 1.8m**



**Composite
Mirror
Applications Inc.**

Deformable CFRP Mirrors

Research and Development Capability

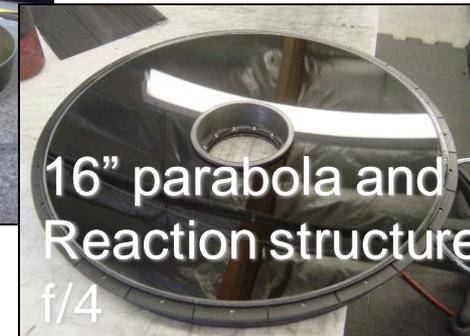
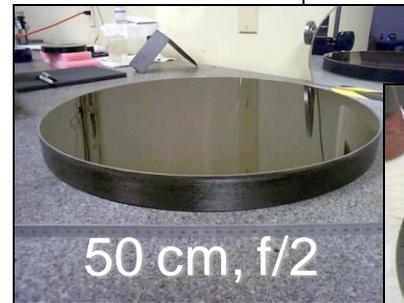
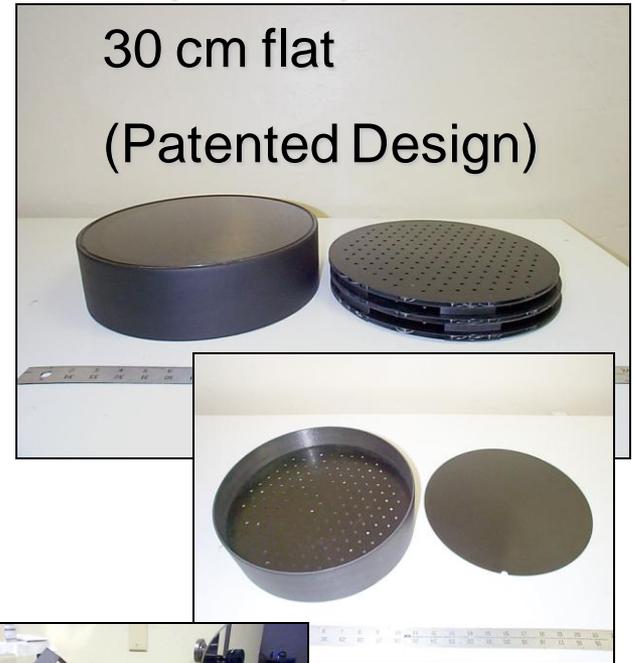
Lightweight Deformable Mirror Technology



Adaptive Optics

30 cm flat

(Patented Design)





**Composite
Mirror
Applications Inc.**

Telescope Options



13-inch RC
system



16-inch
Cassegrain
system



1m Cassegrain
system



1.4m
Cassegrain
system

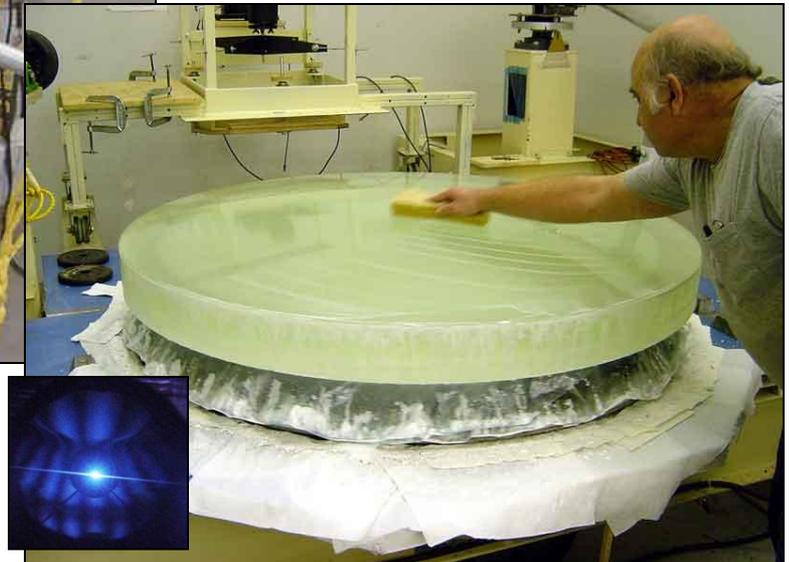
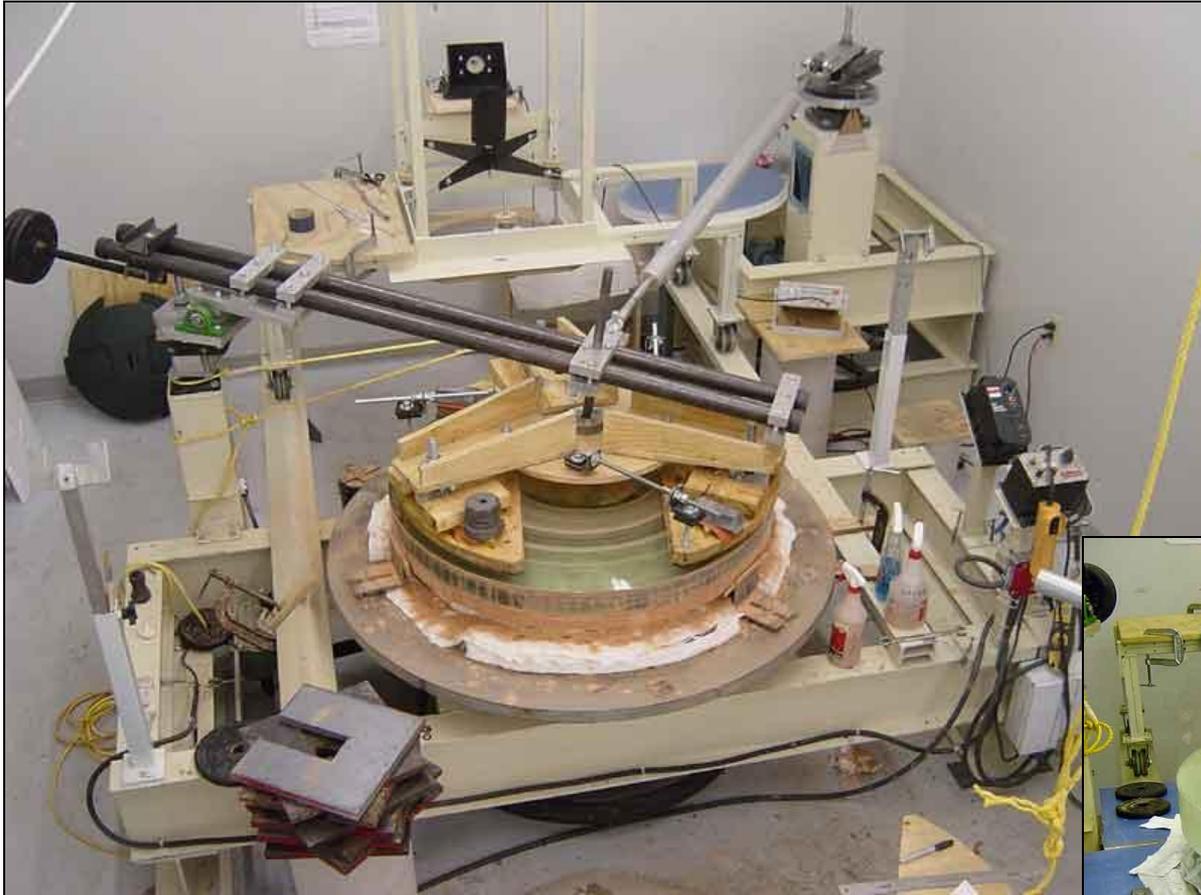


**Composite
Mirror
Applications Inc.**

Optical Fabrication

Convex Optical Mandrels

Convex glass mandrels are essential to the production of CFRP mirrors. CMA has a need for various sizes and radii. Shown, left, is our 2m grinding table with a 1m parabolic Pyrex mandrel under fabrication. 1.4m parabola shown below, optical figure of the 80% zone, ready for final blending.

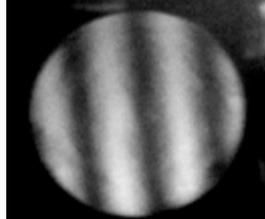
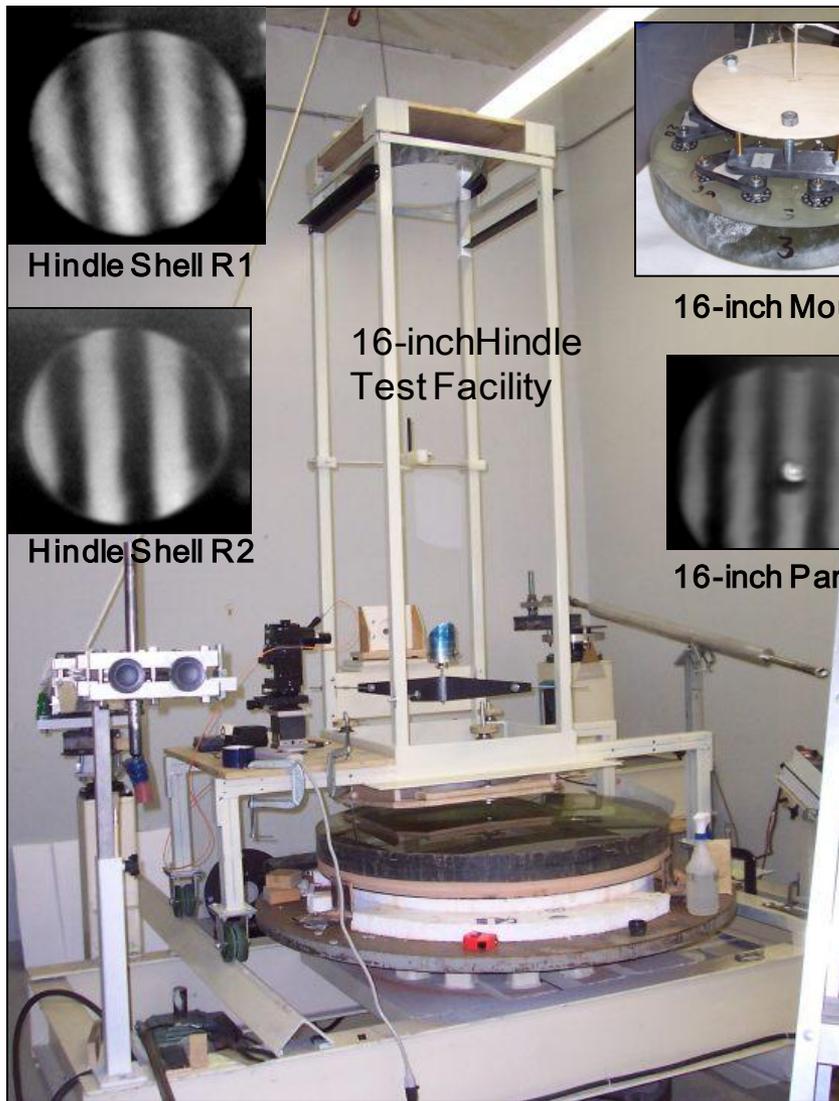




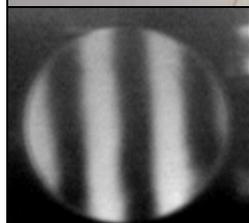
**Composite
Mirror
Applications Inc.**

Optical Metrology

Convex Primary Mirror Mandrels



Hindle Shell R1

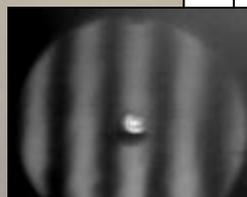


Hindle Shell R2

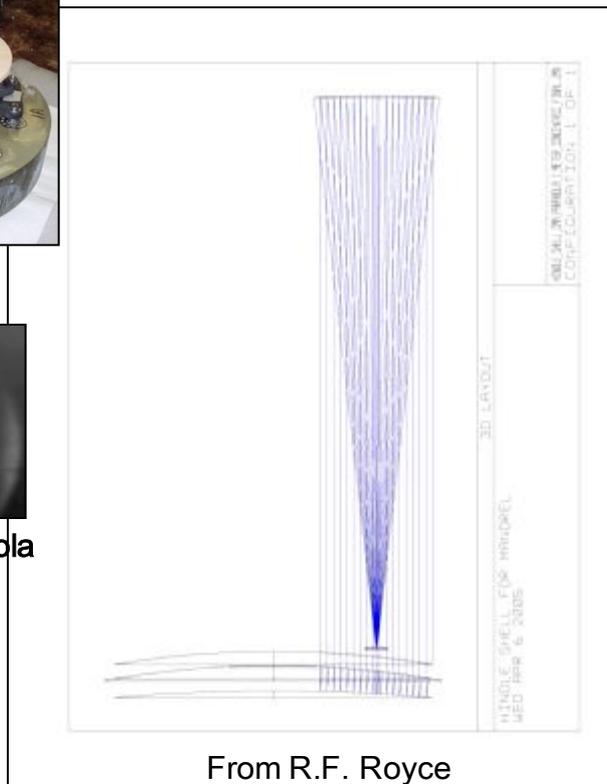
16-inch Hindle
Test Facility



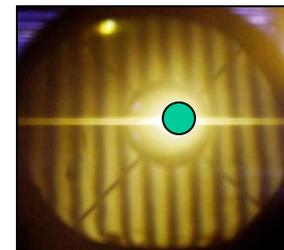
16-inch Mount



16-inch Parabola



ZEMAX 3-D of the
Hindle Null Test for
240-inch ROC
parabola



Final Figure

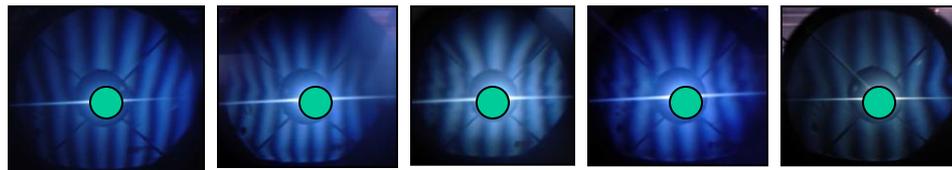
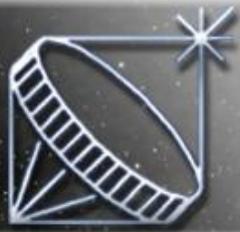
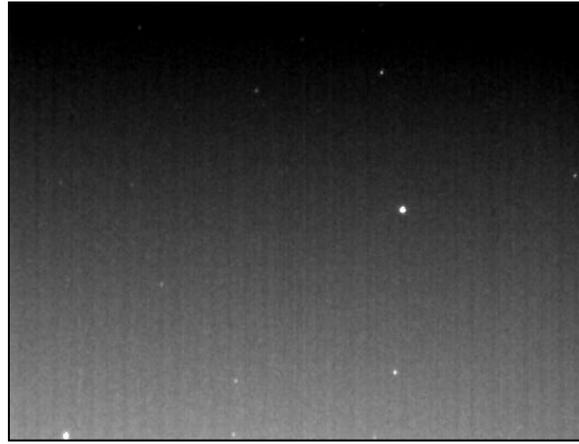
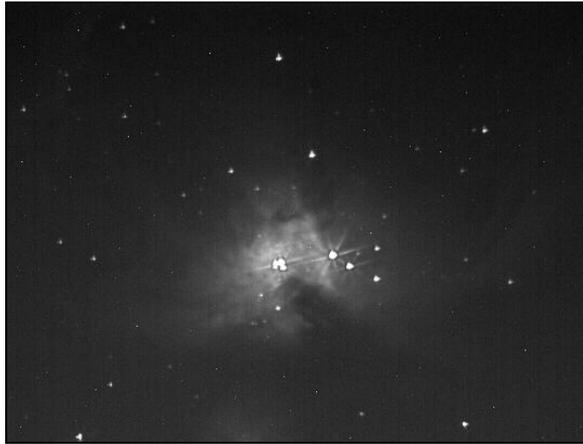


Figure convergence from left to right, bottom
of image is the edge of the mandrel



**Composite
Mirror
Applications Inc.**

**16-inch CFRP
Telescope and Optics**

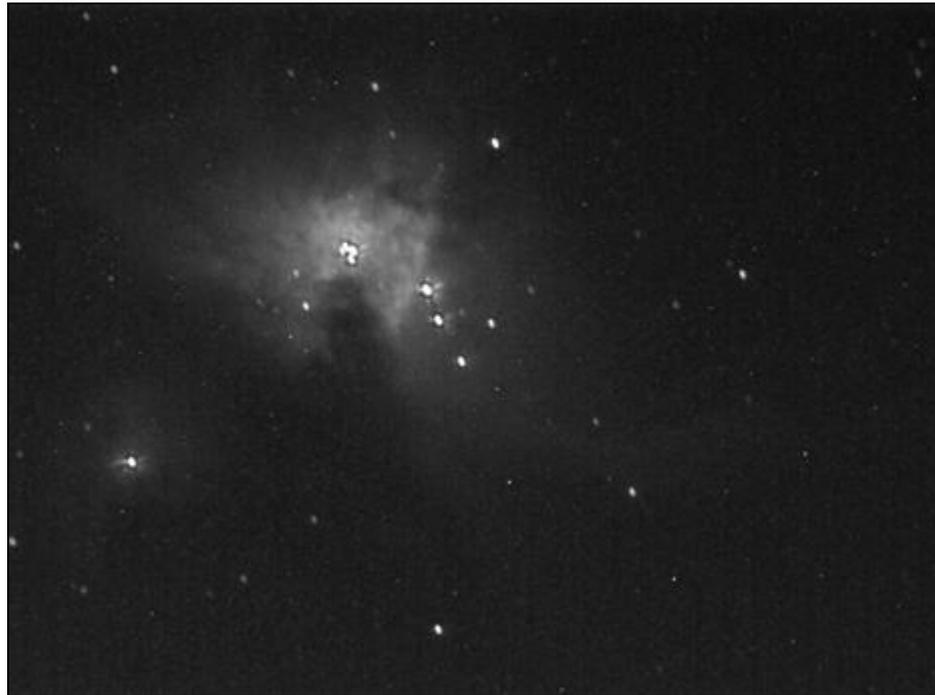


Preliminary astronomical tests with 16-inch CFRP telescope and optics



**Composite
Mirror
Applications Inc.**

**ULTRA CFRP 16-inch f/4.0
Primary Mirror**



16-inch CFRP Primary Mirror, f/4.0

SBIG ST-2000-XM CCD

4-second exp. Orion Nebula

Detector @ 1.03°C

01-24-05, Tucson valley

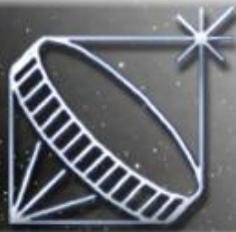
16-inch Meade Glass Primary Mirror, f/4.5

SBIG ST-2000-XM CCD

4-second exp. Orion Nebula

Detector @ 1.03°C

12-14-04, Tucson valley



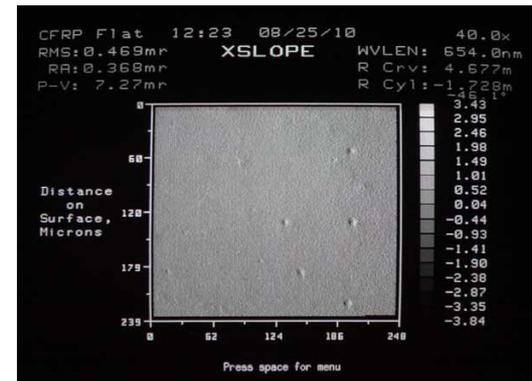
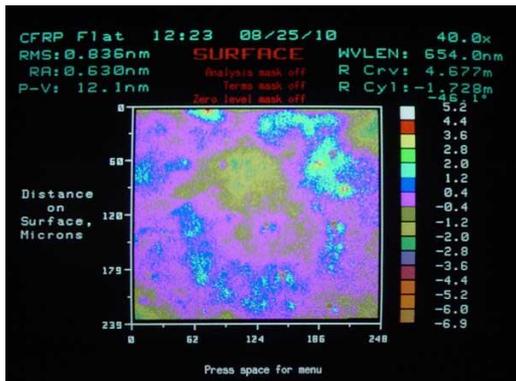
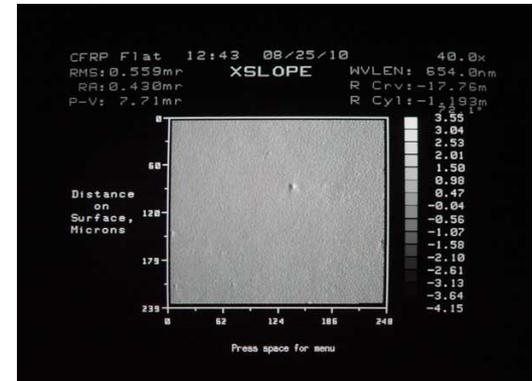
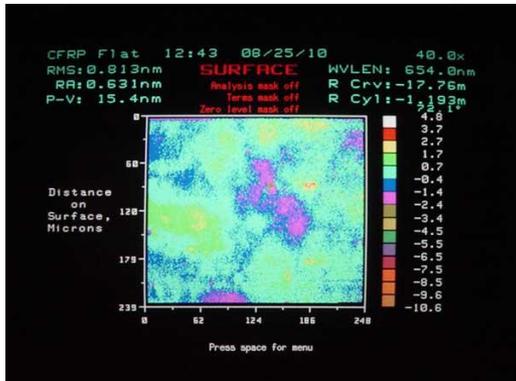
Composite
Mirror
Applications Inc.

CFRP Optical Performance

Roughness Measurements of Flat CFRP Mirror



Roughness data taken from TOPO 3-D, Data showing ~ 8 Angstroms rms directly replicated on CFRP flat from Pyrex mandrel.

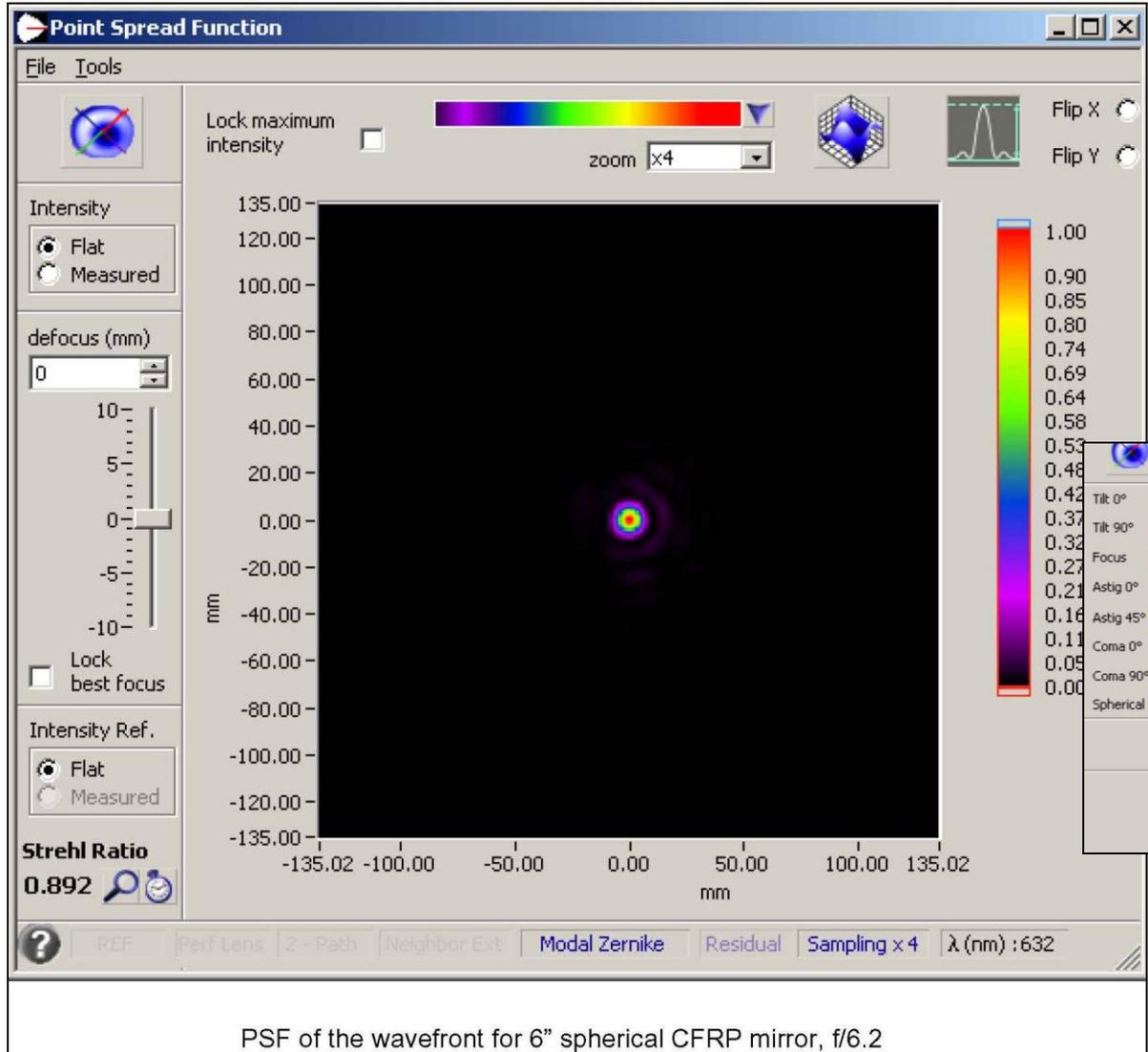




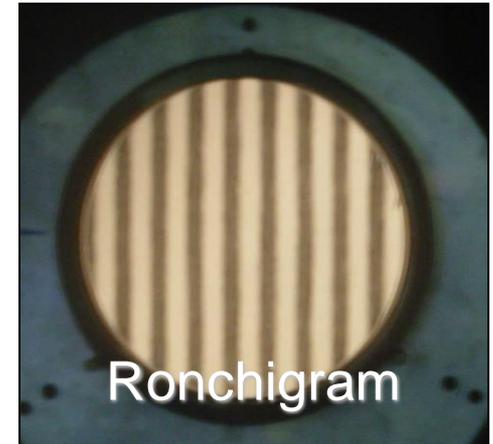
**Composite
Mirror
Applications Inc.**

CFRP Optical Performance

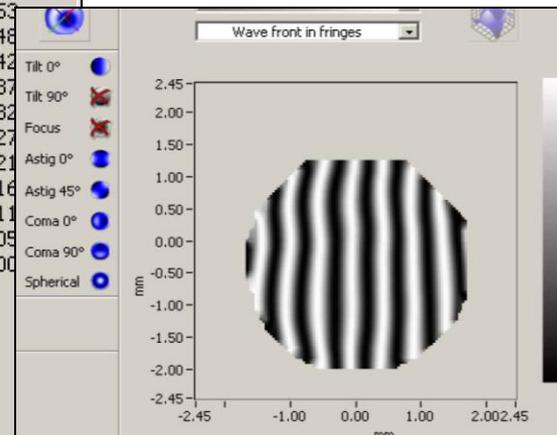
Shack-Hartmann Wave Front Sensor, 6-inch
CFRP Sphere



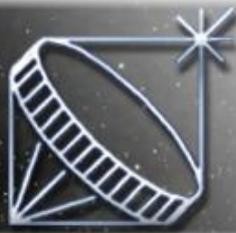
PSF of the wavefront for 6" spherical CFRP mirror, f/6.2



Ronchigram



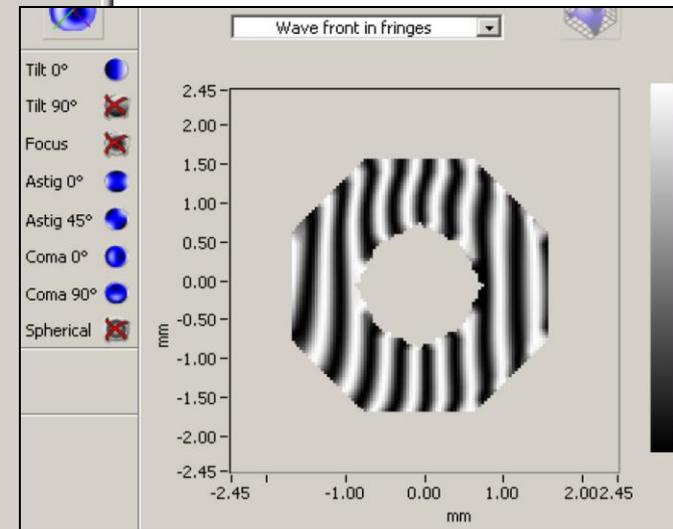
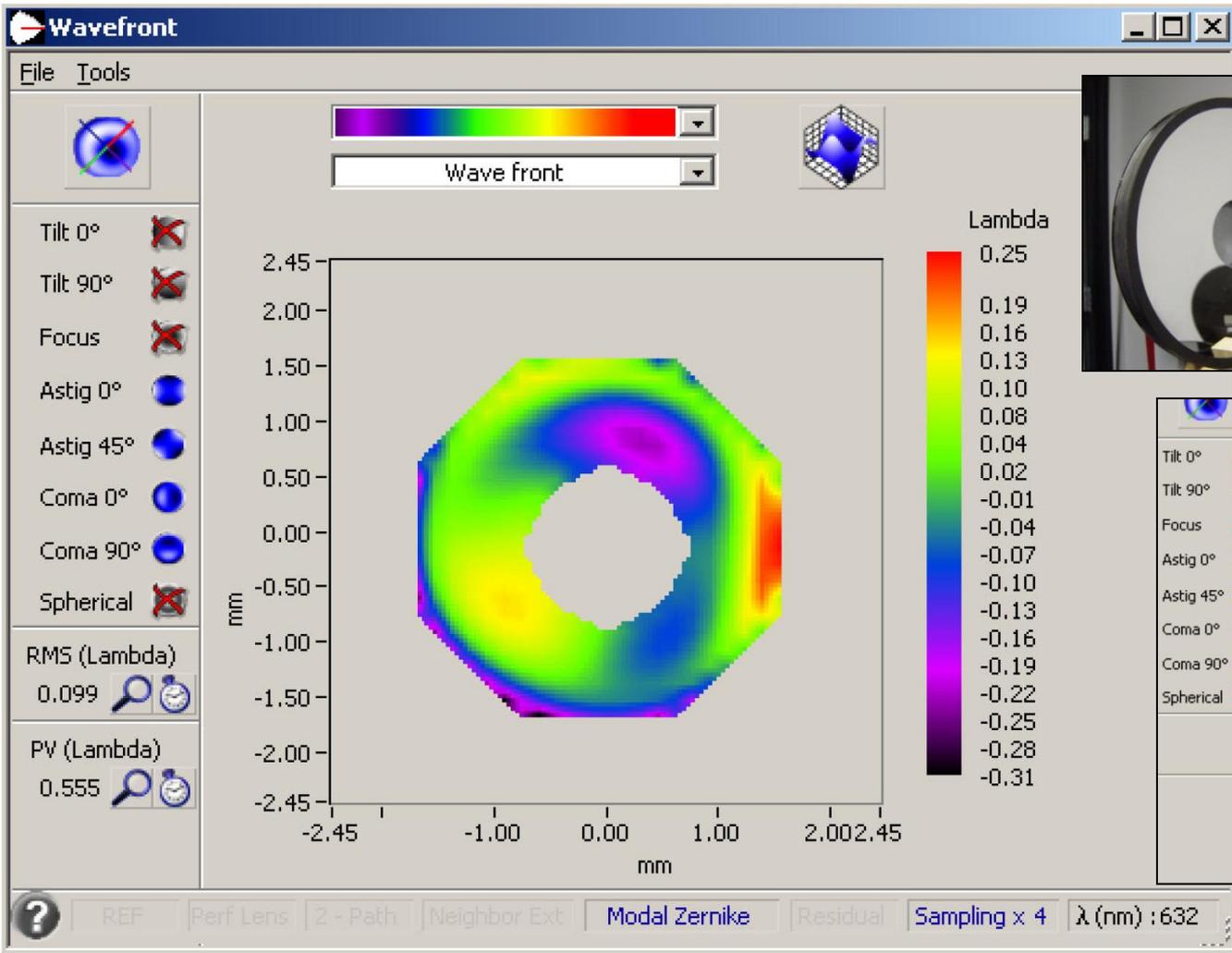
0.365 λ P-V @
 $\lambda=632\text{nm}$



**Composite
Mirror
Applications Inc.**

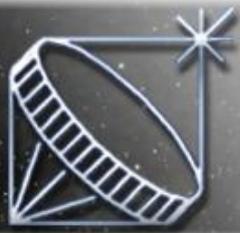
CFRP Optical Performance

Shack-Hartmann Wave Front Sensor,
16-inch CFRP Parabola



0.55 λ P-V @

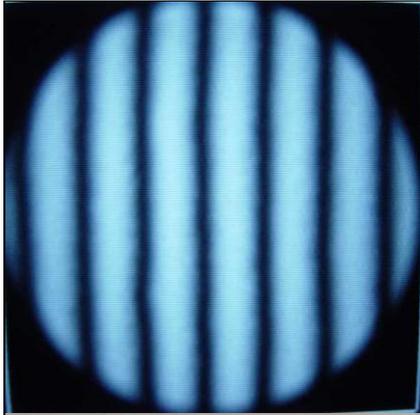
$\lambda=632\text{nm}$



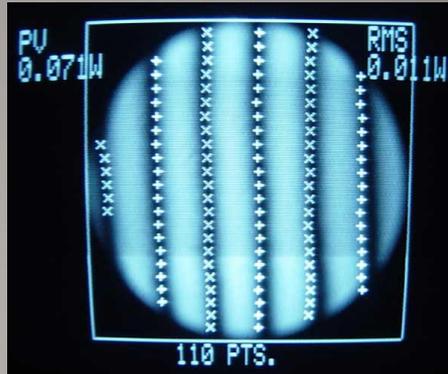
**Composite
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CFRP Optical Performance

Interferograms of Flat CFRP Mirror



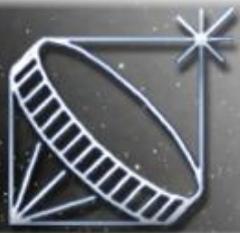
4 inch diameter sub-aperture



Wave front Analysis



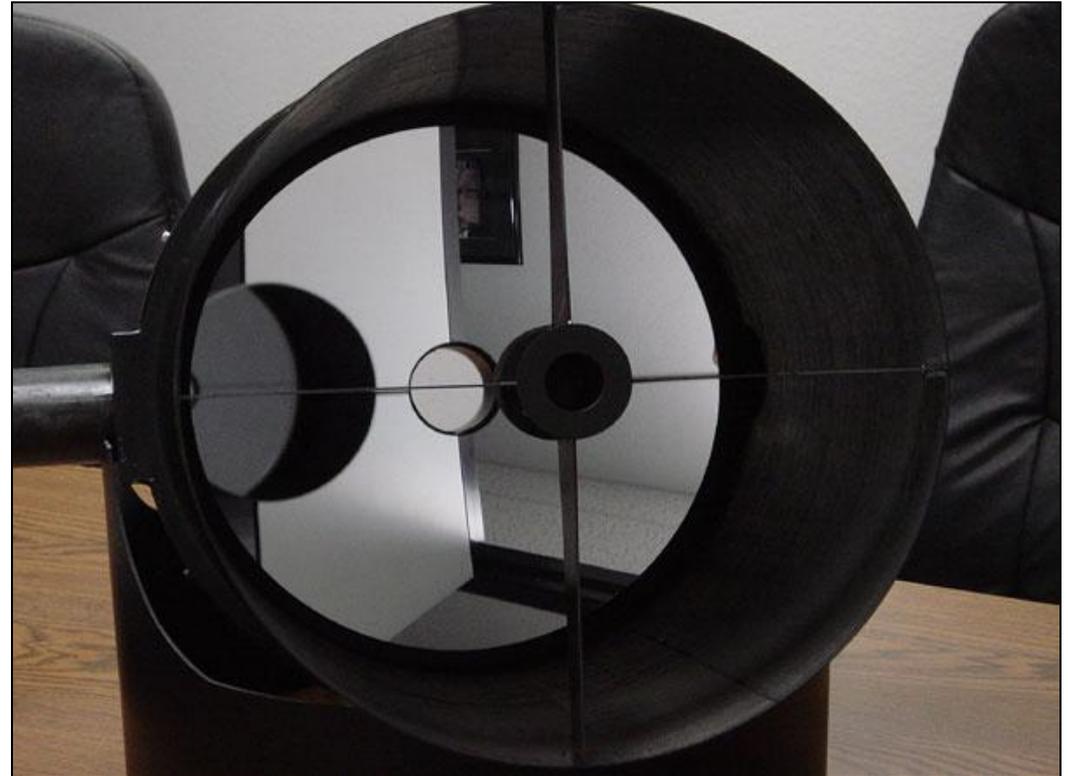
Interferograms at $\lambda = 633\text{nm}$ of 12-inch CFRP flat mirror, Analysis shows better than $\lambda/10$ p-v across 4 inch diameter section. Interferograms taken on Zygo Mark III.



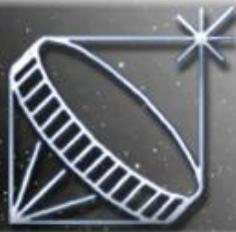
**Composite
Mirror
Applications Inc.**

LiteStar 330

330mm RC Telescope

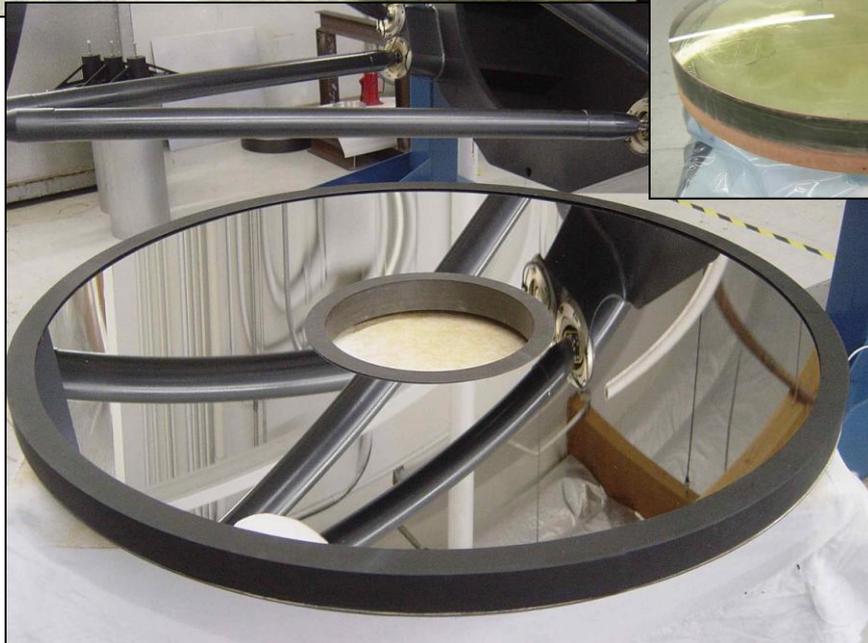
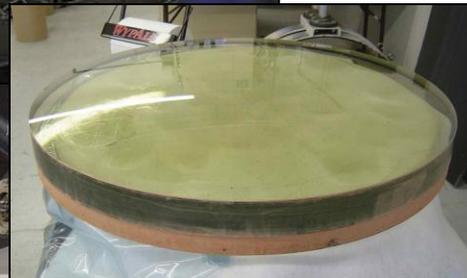
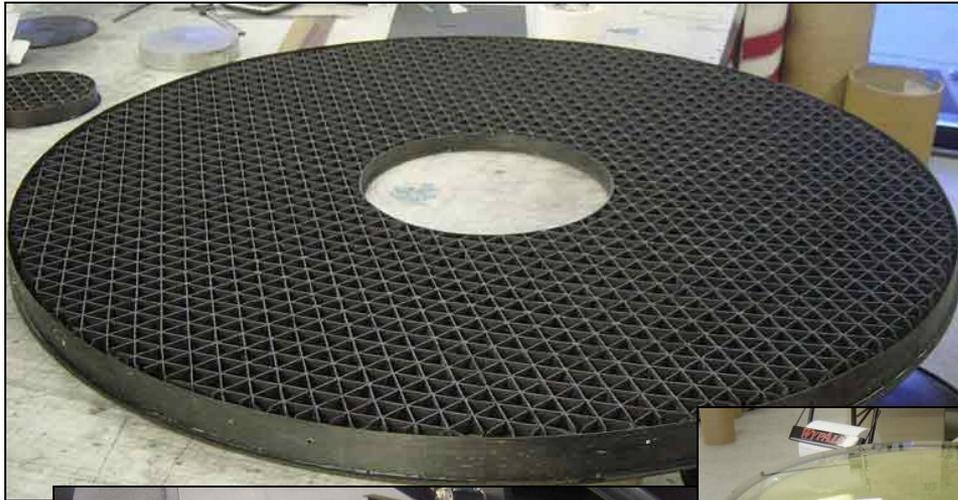
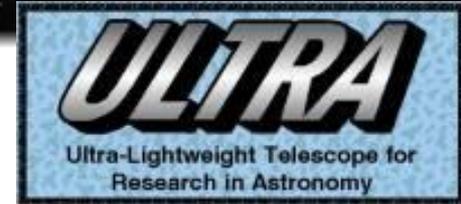


**CMA's Prototype, All-CFRP
composite telescope, weight with
optics 3 kg**

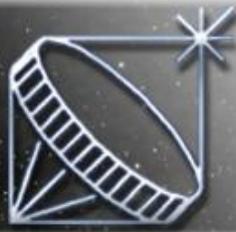


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ULTRA 1m CFRP Optical Primary Mirror



Top image is the ULTRA CFRP 1m primary mirror internal structure, all CFRP construction. Center images shows the glass convex parabolic mandrel. Below is an image of the mirror just after coating. Optical measurements are currently underway and are expected to be of fractional-wave performance in the visible. Mirror weight is 27 lbs.



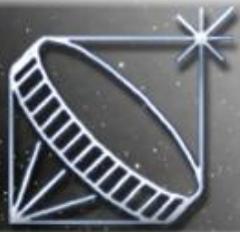
**Composite
Mirror
Applications Inc.**

ULTRA 1m CFRP Telescope



ULTRA 1m all-CFRP composite optical telescope assembly (OTA) for ground-based astronomy. Telescope is shown with 27 pound 1m primary mirror. OTA weight with optics is 175 lbs. First mode frequency for the entire structure is was measured at 50 Hz., 6-axis M2 Hexapod control,



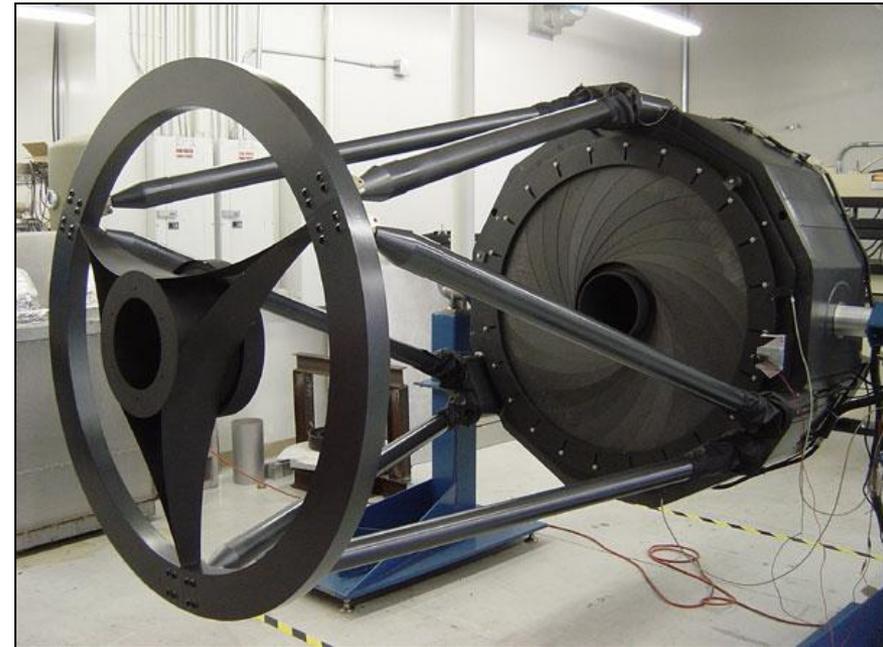


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ULTRA 1m CFRP Telescope



Back End, Instrument package



Completed Telescope



Composite Mirror Applications Inc.

NRL 0.4m CFRP Optical Telescope and Mount



CMA has produced and delivered an all-CFRP composite telescope, and Az-EI mount for the Naval Research Laboratory, NRL. The telescope is an f/10 Cassegrain design with CFRP optics weighing 22 lbs total. The mount is piezo actuator driven for fast tracking capability.



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NPOI 1.4m CFRP Optical Telescope



NPOI, Anderson Mesa

3-D Drawings of the
NPOI System



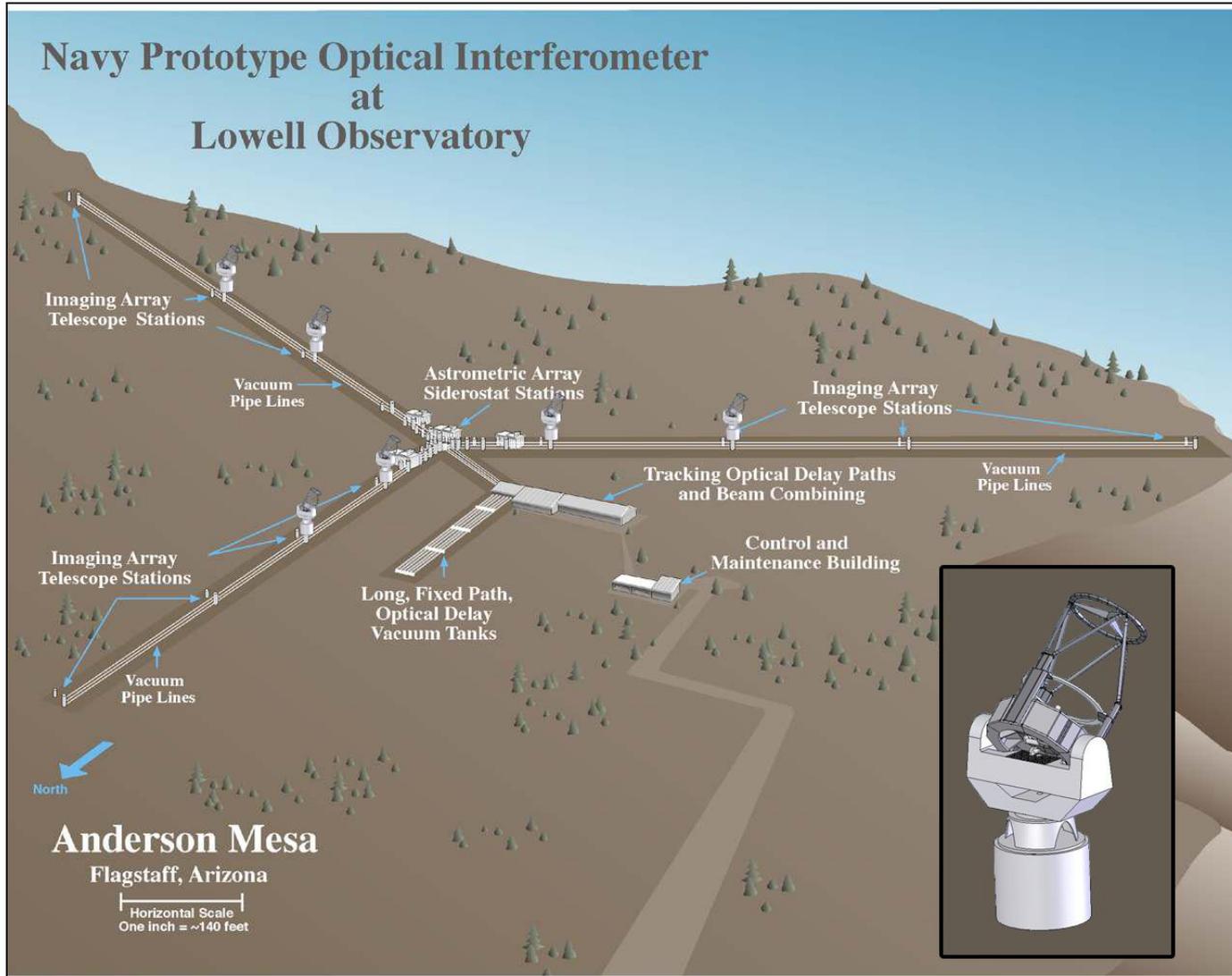


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NPOI 1.4m CFRP Optical Telescope



Navy Prototype Optical Interferometer at Lowell Observatory





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1.4 meter NPOI Upgrade Project



NPOI Upgrade Team

NRL

CMA

NAU

Project Management

**S.R. Restaino
R. Romeo**

Optics
(design and specs)

**R. Martin
T. Martinez
S. Restaino
R. Romeo**

Mount

**J. Clark
R. Martin
R. Romeo
E. Penado
J. Walton**

Enclosure/Forest
Service

**J. Clark
E. Penado
J. Walton
P. Wood**

Control System

**J. Andrews
R. Martin
D. Payne
C. Wilcox**

Material analysis

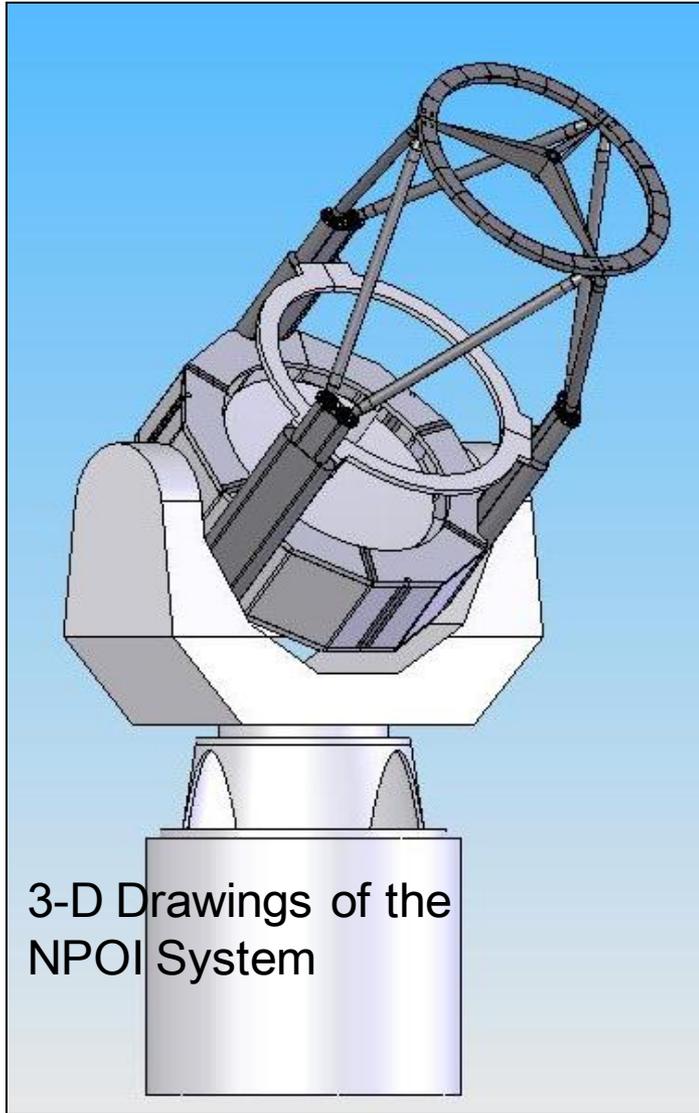
**S. Broome
E. Penado
R. Martin
R. Romeo**



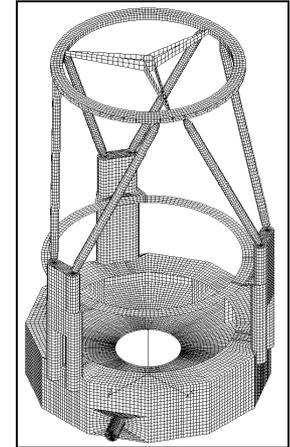
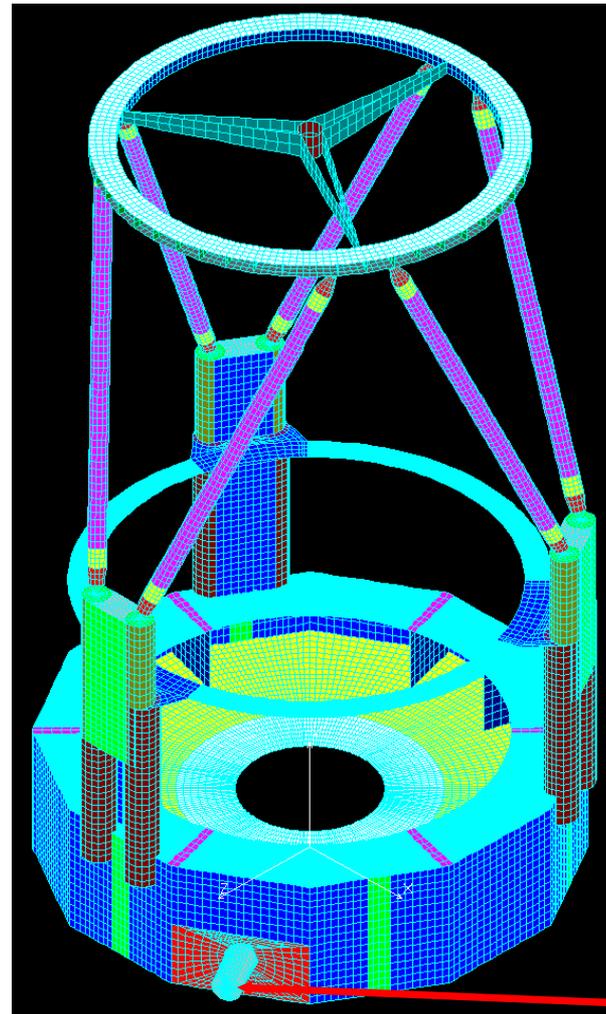
**Composite
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NPOI 1.4m CFRP

Optical Telescope



3-D Drawings of the NPOI System



4-noded composite elements (SHELL4L)

SOLID elements for yoke pin

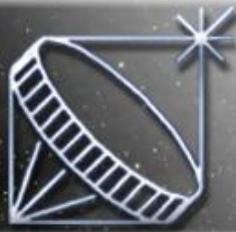
BEAM3D elements for end-fitting bolts

36885 elements

36444 nodes

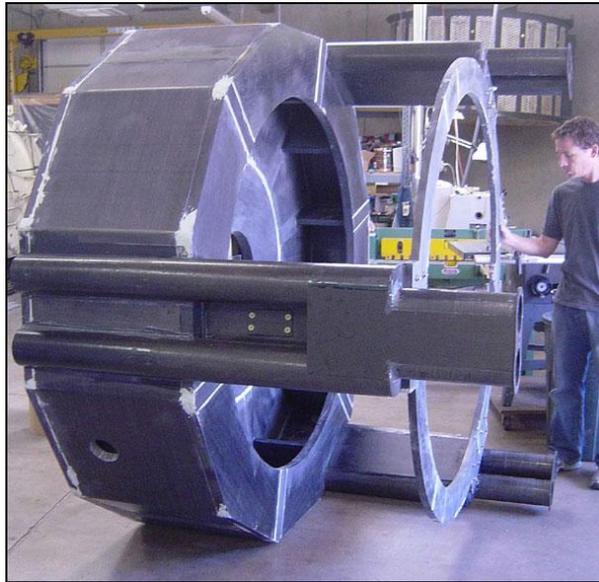
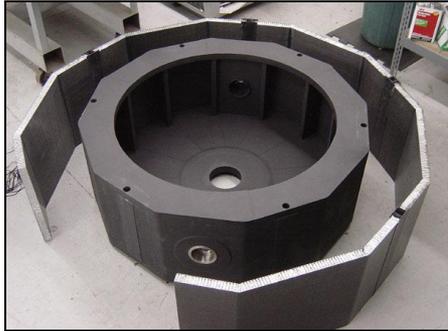
Total weight=250 lb

BC: ends of yoke pins are fixed

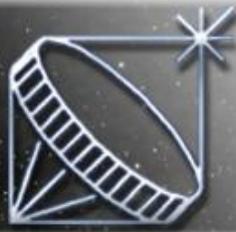


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NPOI 1.4m CFRP Optical Telescope



Various Stages of Fabrication



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NPOI 1.4m CFRP Optical Telescope



Navy Prototype Optical Interferometer (NPOI) 1.4m all-CFRP composite optical telescope assembly (OTA), shown in the final stages of assembly. Telescope is produced for the Naval Research Laboratory (NRL) and is the first of at least 3 identical, deployable lightweight telescopes for the interferometer in Flagstaff Arizona. Total telescope weight with optics is 250 lbs.

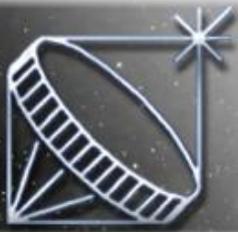


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Applications Inc.*

NPOI 1.4m CFRP Optical Telescope

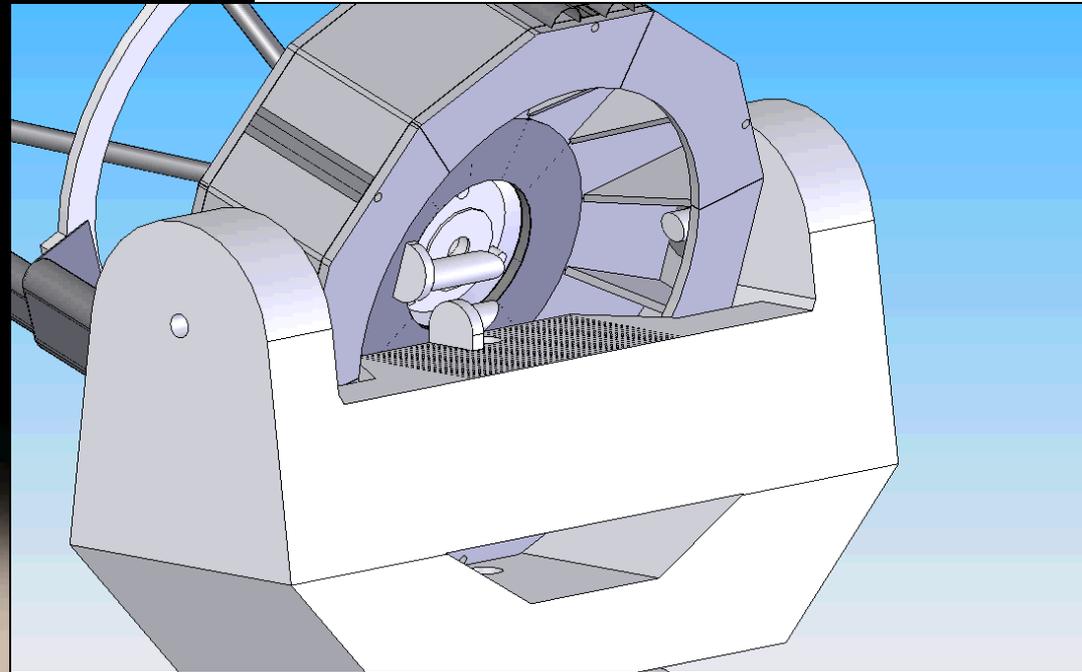
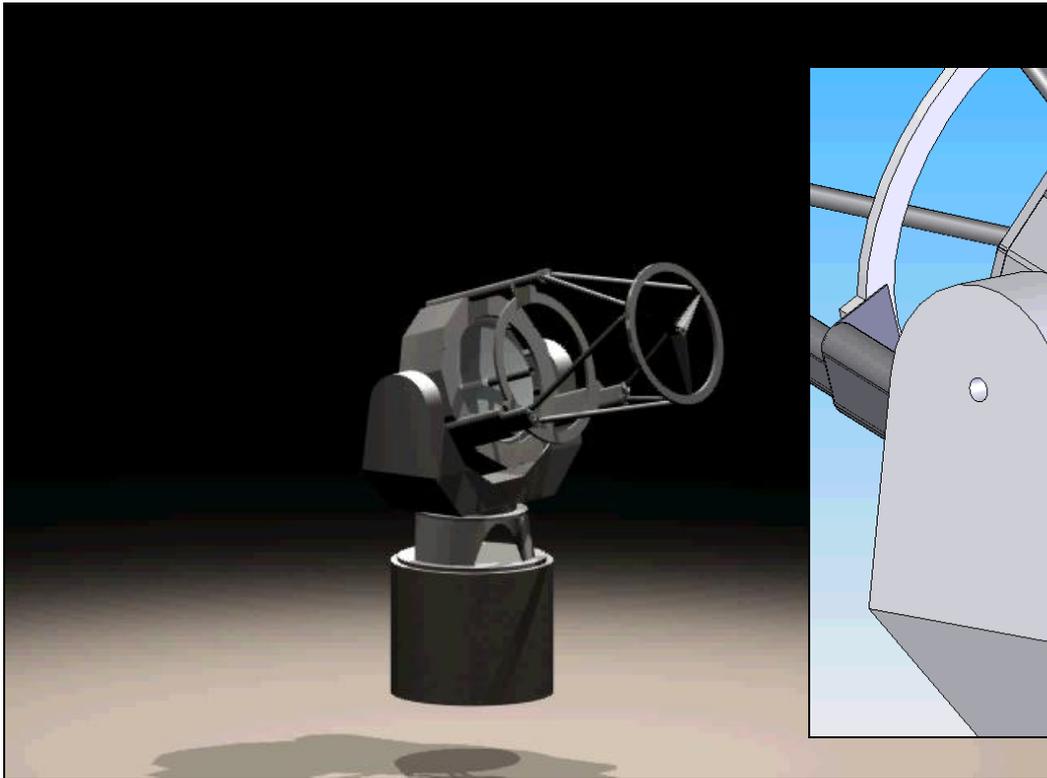


Assembled 1.4m OTA ready for final painting



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NPOI 1.4m CFRP
Optical Telescope Mount



Designs for the 1.4m AZ-EI Mount



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Applications Inc.*

NPOI 1.4m CFRP
Optical Telescope Mount



Status of NPOI 1.4-m Telescope

- AZ-EL Mount is under construction
- Drive elements on order
- Mandrel for Primary is being completed

Still 3-4 λ in figure accuracy